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Probing Pomeron Structure at Fermilab

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PROBING POMERON STRUCTURE AT FERMILAB

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ABSTRACT

Using the CDF detector, dijet and W production with rapidity gaps has been searched for as evidence for hard-pomeron induced diffraction. Diffractive W's are sensitive to a pomeron with a hard-quark structure, while diffractive dijets are sensitive to both hard-gluon and hard-quark structure. No evidence of diffractive W's has been found down to the few percent level and the fraction of diffractive dijets is measured to be $(-0.30 \pm 0.37)\%$, or consistent with zero.
The existence of colorless exchange between jets has been confirmed. Both the D0 and CDF detectors show a statistically significant excess of dijet events with rapidity gaps between the jets at the level of 1-2% of all dijets.

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1. Introduction

Although QCD is accepted as the fundamental theory of hadronic interactions, Regge theory is often used to describe the total, elastic, and diffractive hadronic cross sections using the pomeron (P) trajectory. [1,2] There is recent experimental evidence in single diffractive (SD) events that the pomeron may have partonic structure. The UA8 experiment has observed dijet events associated with a recoil proton [3] and the HERA experiments are also finding evidence for hard scattering in events with large rapidity gaps. [4,5]

Measuring the pomeron structure in terms of quarks and gluons within single diffraction is possible if one assumes factorization. [6] As shown pictorially in Fig. 1, a proton (unless specified, either p or $\bar{p}$) has associated with it a flux of pomerons which interacts with the other proton to produce a diffractive event. The SD cross section is given by

$$\frac{d^2\sigma_{SD}}{d\xi\, dt} = \sigma_T^{\mathcal{P}p} \;\; f_{\mathcal{P}/p}(\xi,t).$$

The pomeron flux factor $f_{\mathcal{P}/p}(\xi,t)$ gives the probability of getting a pomeron with a certain (ξ,t), where ξ is the fraction of the proton's momentum carried by the pomeron, and t is the square of the 4-momentum transfer or the negative mass squared of the virtual pomeron. The pomeron-proton total cross section $\sigma_T^{\mathcal{P}p}$ is assumed to be constant.

Using this technique, predictions were made [7] for the rate of diffractive W's assuming three types of structure functions: *soft gluon* $xf_{g/\mathcal{P}}(x) = 6(1-x)^5$; *hard gluon* $xf_{g/\mathcal{P}}(x) = 6x(1-x)$; and *hard quark* $xf_{q/\mathcal{P}}(x) = \frac{6}{4}x(1-x)$. If the pomeron is described by the hard-quark structure function, then 17% of all W's produced at tevatron energies would be diffractive! Using the same calculation, with a hard-gluon pomeron structure, would predict that 3.8% of all dijet events are diffractive. The preliminary results of a search for diffraction within CDF W and dijet samples are presented in this paper.

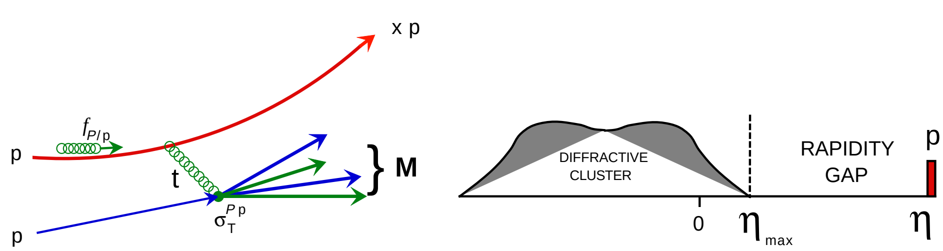

Figure 1: Single Diffraction

An experimentally, if not physically, related phenomenon is the possibility of a color-singlet exchange between interacting partons. This process has been predicted to produce rapidity gaps between jets in 0.3 to 3.0% of the dijet events. [8–10] In normal quark or gluon color octet exchange, there are soft-hadrons produced by the color field in the region between the jets. The experimental observation of color-singlet exchange requires a significant excess of zero, or low particle multiplicity between the jets compared to that expected from color-octet exchange. The two previously published results are: a 95% CL limit by D0 that less than 1.1% of dijet events contained rapidity gaps [11]; and an observation by CDF that $(0.85 \pm 0.12^{+0.24}_{-0.12})\%$ of dijet events, with the track multiplicity integrated over $\Delta\eta > 0.8$ between the jets, had significant zero-track or rapidity gap events. [12]

Single diffraction can be identified by a recoil proton, as in experiment UA8, or by the edge of the event multiplicity $\eta_{\max}$ (Fig. 1). The characteristic that is used to identify colorless exchange for the results presented here is the appearance of a region in rapidity without low-energy hadrons. Technically, events with "rapidity gaps" are defined by zero track or tower multiplicity, where the multiplicity is the number of tracks of towers above a p_T or E_T threshold, within a specified region of rapidity space.

2. Diffractive W measurement

A sample of approximately 3500 W's, taken with the CDF detector during the 1992-93 Tevatron run, was used to search for evidence of diffractive W's. For both the diffractive W and dijet samples, the data was taken without the usual requirement of a forward, east-west coincidence in order to accept diffractive events, and only one primary vertex (interaction) per event was allowed in order to assure the survival of any rapidity gap. The standard W selection requirements [13)] on lepton identification, lepton E_T, and missing E_T, were used to produce three subsamples of data: central ($|\eta| < 1.1$) electrons; plug ($1.1 < |\eta| < 2.4$) electrons; and central muons.

Diffractive events will tend to have zero multiplicity at high rapidity in the direction of the recoil proton (Fig. 1). The definition of the gap region multiplicity is, for both the diffractive W and dijet searches, the number of calorimeter towers (either EM or hadron) with $E_T > 200$ MeV within the region $2.0 < |\eta| < 4.2$. The CDF calorimetry has towers that are segmented $\Delta\eta \times \Delta\phi = 0.1 \times 0.26$ for $|\eta| < 1.1$ and 0.1×0.087 out to $|\eta| < 4.2$. Figure 2a shows the tower multiplicity in the gap region for the central electron W sample. There are clearly events with multiplicity gaps, although the zero bin may be consistent with normal statistical fluctuations of the overall distribution. In order to extract any significant diffractive signal for events with a multiplicity gap, additional diffractive characteristics are used.

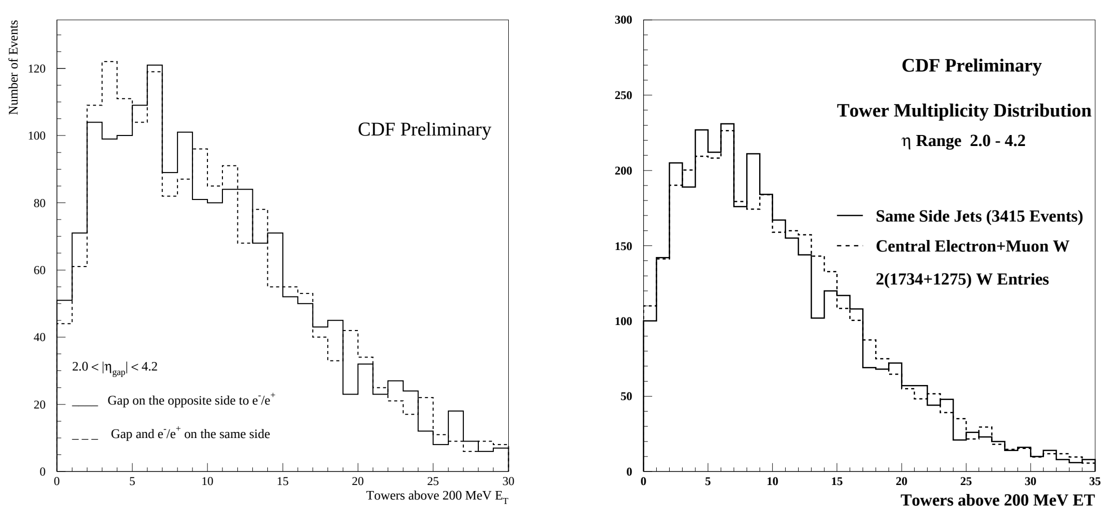

Figure 2: left to right **a)** Gap multiplicity opposite, and the same side as, e^-/e^+ for W events. **b)** Gap multiplicity opposite dijet, and W sample.

In the diffractive event topology (Fig. 1) the W, and the observed lepton to a lesser extent, will tend to be produced with a rapidity in the hemisphere opposite to the rapidity gap. In Fig. 2a, the two multiplicity distributions are for the gap region opposite the electron rapidity and on the same side. The presence of diffractive W's would produce a net excess in the zero bin for the "opposite" multiplicity distribution.

Another feature of diffractive W's would be a correlation between the W-lepton charge and the direction of the rapidity gap. Within a diffractive event in which the pomeron interacts with the $\bar{p}$, and therefore the rapidity gap is in the proton direction, a naive argument would predict that the W charge is biased two-to-one negative by the two $\bar{u}$-quarks in the $\bar{p}$, while the pomeron is naturally flavor symmetric.

The three subsamples of data were independently analyzed looking for both charge and rapidity correlations in the zero multiplicity bins, and no excess consistent with diffraction was observed. At this time no limit is presented because the Monte Carlo acceptance for diffractive events has yet to be determined. However the limit on diffractive W's will be of order a few % of the total W sample.

3. Diffractive dijet measurement

The search for diffractive dijets was similar to that of the W's, and used a sample of 3415 forward dijet events taken with the CDF detector during the same running period. The events were selected by requiring that both jets have $20 < E_T < 60$ GeV and $|\eta| > 1.8$, and be on the same side in η and back-to-back in ϕ to within one radian. The multiplicity in the gap region ($2.0 < |\eta| < 4.2$) opposite in η from the dijets is shown in Fig. 2b, with the W gap multiplicity for the same region superimposed.

Figure 2b shows no excess of events with low gap multiplicity compared with the W multiplicity, which contained no sign of diffraction as shown above. The measured fraction of diffractive dijet events is $(-0.30 \pm 0.37)\%$, or consistent with zero.

4. Rapidity gaps between jets

The D0 search for rapidity gaps between jets required both jets to have $E_T > 30$ GeV and $|\eta| < 3.2$ and the final sample contained 15,200 dijet events with $\Delta\eta > 2.7$ between the two leading jets. The multiplicity in the η-region between jets was defined as the number of EM calorimeter towers with $E_T^{em} > 200$ MeV isolated from the jets by $\delta\eta = 0.7$. The D0 calorimetry has towers segmented by $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ out to $|\eta| < 4.1$. Figure 3a shows the tower multiplicity between jets, for dijets separated by $\Delta\eta > 3$. There is a 41 σ excess at low tower multiplicities (0-3) over the extrapolation of a negative binomial fit to the whole multiplicity distribution! The excess gap events represent $(1.4 \pm 0.2)\%$ of the dijet sample.

It has been verified that the negative binomial function fits well to the tower multiplicity distribution when no color-singlet signal is expected, for instance same-side jets and 3-jet events. The tracking multiplicity between jets also shows an excess of low multiplicity events, although there is no p_T information.

The CDF search uses the central tracking to count the multiplicity of charged tracks with $p_T > 300$ MeV between jets within $|\eta| < 1.1$. The dijets were selected in the same way as the diffractive dijet search described above, with the exception that the jet rapidities were required to be in opposite hemispheres. Figure 3b shows the track multiplicity between the jets for these events. The evidence for the color-singlet signal is the clear excess in the zero bin, with no need for fitting! The non-singlet contribution (shown dashed in Fig. 3b) is subtracted by using the analogous track multiplicity from the diffractive dijet sample. The excess gap events were measured to be $(2.0 \pm 0.7)\%$ of the opposite-side jet sample.

The signal is also evident as an excess in the low multiplicity bins (0-3) of the tower multiplicity distribution between the jets, when compared to the diffractive dijet multiplicity. The signal shows up in multiplicities 0-3 with towers, as opposed to zero with tracks possibly because: the towers are sensitive to γ's from π^0; the towers have a lower threshold (tower $E_T > 200$ MeV compared to track $p_T > 300$ MeV); the tracks are restricted to $|\eta| < 1.1$ and therefore more isolated from the jets than the towers; and it is easier to fake a tower than a track.

The signal in both the D0 and CDF analysis was shown to be insensitive to reasonable variations in E_T or p_T threshold and $\Delta\eta$-interval.

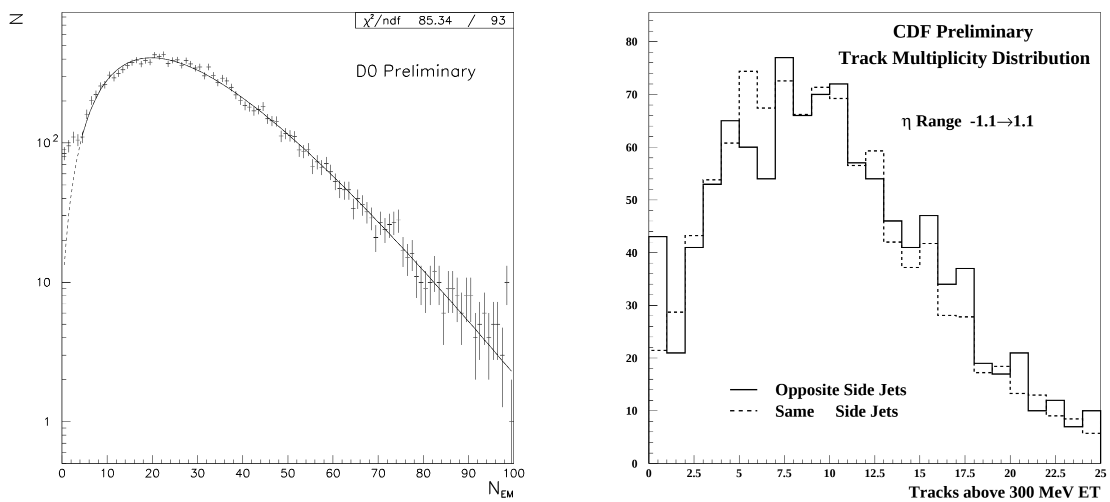

Figure 3: left to right **a)** D0 Tower multiplicity between jets compared to negative binomial fit. **b)** CDF Track multiplicity between jets compared to same-side jets.

5. Conclusions

There is mounting kinematic evidence that the pomeron contains "hard" partonic structure, although whether it is consistent with quark or gluon structure has not been determined. The search for hard processes associated with diffractive rapidity gaps at CDF has indicated a limit of a few % of the total W sample, and a measurement of $(-0.30 \pm 0.37)\%$, consistent with zero, of same-side dijet sample. These results are below those predicted by Bruni and Ingelman [7)] for a pomeron that obeys the momentum sum rule.

There is an alternative parameterization in which the pomeron flux is interpreted as a probability, [14)] and therefore bounded to less than one pomeron per interaction. In this case the diffractive W production, for a hard-quark pomeron structure is predicted to be $\sim 2.8\%$, which is near the current experimental limit. The diffractive dijet prediction, for a hard-gluon structure, is of order $\frac{1}{2}\%$, also near the current experimental sensitivity. In this case a more sensitive search for diffractive processes is required to determine the structure of the pomeron.

The existence of significant rapidity gaps between jets has been definitely established. The D0 signal shows an excess of events with low tower multiplicity within the rapidity interval between jets at a level of $(1.4 \pm 0.2)\%$ of all dijets analyzed. The significance of the signal is 41 σ over the color-octet (negative binomial) assumption. Using tracks, CDF has a 4.5 σ significant effect at the level of $(2.0 \pm 0.7)\%$ of all opposite-side dijets. Although the two experiments have different dijet samples, different definitions of multiplicity, and different multiplicity intervals, the signals are consistent with each other. The natural interpretation is color singlet exchange, and the range of predictions [8–10)] are consistent with the measurements.

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